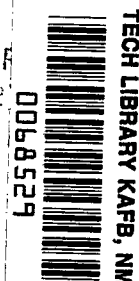


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by A. G. Kuznetsov, et al.

*Paper presented at the XV International Astronautical Congress,
Warsaw, September 7-12, 1964*



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EFFECT ON THE BODY OF PROLONGED EXPOSURE TO CONDITIONS OF ARTIFICIAL ATMOSPHERE

A. G. Kuznetsov, N. A. Agadzhanyan, A. G. Dianov, and S. G. Zharov

Preservation of normal work capacity and health in spacecraft crew members requires the maintenance of sufficient total pressure and an optimum ratio of oxygen, carbon dioxide, and other gases. It is also important to eliminate the irritating, foul smelling, and toxic substances formed as the result of the vital activities of humans and by the use of equipment systems of the vessel from the atmosphere of the sealed cabin. This is why the problem of creating a gas medium environment for humans, permitting prolonged exposure in a sealed chamber of limited dimensions, has great theoretical and practical importance for astronautics and is in essence a medical-biological problem which is new in principle, and one which has arisen due to the rapid development of rocket technology.

In the Soviet Union experience has been gained by the use in the sealed cabins of the "Vostok" ships of atmospheres whose characteristics closely resemble those of the terrestrial atmosphere. However, in the interest of finding ways of broadening the biological and technological capabilities for sustaining human life in space, the question of creating gas mixtures for spacecraft cabin atmospheres which will be optimal for various total pressures and flight periods has arisen.

A limited number of works dealing with this problem exist (D. I. Ivanov, V. B. Malkin, V. L. Popkov, Ye. O. Popova, I. N. Chernyakov, 1961; V. P. Zagryadskiy and others, 1961; Belch, Morgan, and Thomas, 1961).

In lengthy experiments conducted both under terrestrial conditions and under conditions of reduced pressures (to 198 mm Hg), we have obtained data which may be of use in formulating a microclimate for aircraft cabins.

The dynamics of gas metabolism, cardiovascular system functions, and peripheral blood composition were studied in two subjects who were exposed for many days to normal terrestrial conditions and to conditions of lowered barometric pressure (with a partial oxygen pressure of 160-170 mm Hg). Using the combined method of Douglas and Holden and a spirometabolograph the gas metabolism studies were conducted on the subjects in a state of rest (basal metabolism), and during and after physical exertion (40 deep knee bends in 22 min). In addition, respiratory minute volume (RMV), vital capacity, and supplementary and reserve air were measured for more thorough study of the respiratory functions.

The results of experimental investigations have shown that during prolonged sojourns in an artificial atmosphere, the subjects' oxygen requirement while at rest decreases by 6 percent to 17 percent after one month, and by 34 percent to 36 percent after two months. In addition, there occurred a somewhat less pronounced decrease in CO_2 excretion, and a gradual increase in the respiratory coefficient from 0.75-0.82 to 0.97-1.1.

The amount of heat generated by the bodies of the experimental subjects decreased by 7.5 percent to 14 percent after one month and by 28 percent to 34.5 percent after two months. RMV decreased by an average of 5 percent to 10 percent after one month of the experiment and 9.5 percent to 25 percent after two months.

Many days' exposure to conditions of lowered barometric pressure produced by the end of the experiment an average increased frequency of cardiac contractions of 8 to 10 beats (20 percent) and a lowering of systolic (by 10 percent to 16 percent) and diastolic (by 7 percent to 8 percent) pressures.

Increased pulse rates at the end of experiments involving prolonged exposure to lowered barometric pressure have also been reported by other authors (D. I. Ivanov, V. B. Malkin, and others, 1961; A. D. Seryapin, 1961; and others).

In analyzing these materials, it must be considered that under conditions of relative adynamia, the cholinergic activity of the vagus nerve is disturbed. The dominance in the present case of adrenoenergetic activity of the sympathetic nerve causes metabolic changes in vessels and tissues (Raab, 1955).

Blood pressure changes during exposure to lowered barometric pressure, consisting of lowered diastolic pressure, simultaneously accompanied by EKG-detectable impairment of cardiac muscle excitability are mentioned in the literature (Morgan, Ulvedal, Belch, 1961).

In our experiments no significant changes in EKG during prolonged exposure of the subjects to "altitude" were noted. Only slight changes in the maximum level of P and R peaks need be noted.

In order to establish the degree of detraining, the functional capacity of the organism in response to measured physical loading, orthostatic tests, and Valsalva's test was determined. The data obtained show that the response reactions of the body to functional tests are dependent on the duration of the experiment. As a rule, at the end of the experiment, increased pulse rates occurred in response to measured physical loading.

This was accompanied by an increase in the length of time required for the pulse to return to the initial rate, and by the occurrence of a "negative phase" in the blood pressure picture, which the majority of authors regard as an indication of cardiovascular system fatigue--sympathetic and vascular instability. (S. S. Mindlin, 1930; B. A. Ivanovskiy, 1935; V. A. Gorinevskaya, 1944).

The observed functional shifts are in all probability related to the general process of asthenia in the body and lowered vascular tone, which are in turn mainly the result of lack of motor activity and lowered afferent impulsation.

Blood studies revealed only minor changes. Only a slight increase in erythrocytes, reticulocytes, and hemoglobin occurs. The increase in the quantity of erythrocytes and hemoglobin is probably due to the slight hemoconcentration which may occur under "high altitude" conditions because of disruption of the water balance.

However, this mechanism of erythrocytosis is apparently not natural. The total number of leukocytes did not exceed the initial limits. During the second half of the experiment the total number of eosinophils decreased 1.5 to 2 times by comparison with the initial figure. Investigation of the phagocyte activity of neutrophils, established that at the end of the experiment the number of phagocytes and the phagocyte index increased. The increase in phagocyte activity preceded the fatigue phase.

The cited changes in gas metabolism, like changes in other physiological functions, were mainly connected with hypodynamia, which had a lowering effect on metabolism. Eight to ten days after the end of the experiment and the return of the subjects to normal vital activities under natural conditions, the gas metabolism function was restored almost to normal.

Analogous data were also obtained in animal experiments. Prolonged (98 days) exposure of animals to conditions of lowered pressure (190 to 200 mm Hg) in an atmosphere of pure oxygen produced no effects dangerous to life or general condition.

We consider that a moderate reduction in barometric pressure with (maintenance of) normal partial oxygen pressure in the respired air has no real effect on the organism, particularly on the functions of the higher centers of the cerebral cortex, respiration, and cardiac activity. And even if rarefaction does have some biological effect on the organism, it is more probable that this operates through the water metabolism.

Inasmuch as the spacecraft cabin atmosphere must possess optimal physiological and hygienic characteristics and satisfy a number of

engineering requirements, the question of the possibility of replacing the nitrogen with helium in the cabin air takes on great importance. Such a substitution would be advantageous both from the physiological and engineering standpoints (reducing the danger of decompression disturbances in case of pressure drops, elimination of harmful effects on humans of induced radioactivity caused by bombardment of the nitrogen molecules by cosmic radiation, and reduction of the launch weight of the spacecraft and the energy expenditure necessary to maintain adequate cabin ventilation).

Up to the present time the effect of helium-oxygen mixture on humans and animals has been studied in the works of both Soviet and non-Soviet authors. Animal experiments have demonstrated the possibility of prolonged (up to two and a half months) exposure to a helium-oxygen medium (Barch, 1934; Cook, 1960; B. M. Savin, 1963; and others). Within a temperature range of $18^{\circ}\text{--}22^{\circ}\text{C}$, helium, which has a high heat conductivity compared to nitrogen, increases the gas metabolism in animals because of increased heat loss. However, if the temperature range of the helium-oxygen medium is raised to $27^{\circ}\text{--}29^{\circ}\text{C}$, the animals display no essential changes whatsoever.

The effect of a helium-oxygen mixture on the human body has been studied only in short-term experiments, lasting no longer than several hours (the use of helium by deep-sea divers, the treatment of certain respiratory ailments, etc.). The results of these studies have demonstrated the possibility of respiration of a helium-oxygen mixture by humans for short periods not only at ordinary, but also at increased pressures (up to 16 atm). However, in these experiments the helium-oxygen mixture was not used as a total environmental gas medium surrounding the subject, but only as a gas mixture for mask breathing. Prolonged experiments have not been conducted so far with the helium-oxygen mixture used as an environmental medium for humans.

In the present study, the possibility of a prolonged sojourn by humans in a sealed cabin where nitrogen has been replaced by helium is investigated. Two long experiments, lasting a total of 22 and 30 days, were conducted with the participation of two subjects (the subjects were exposed to a helium-oxygen medium for 10 and 25 days respectively). The experiments were conducted in a hermetically-sealed cabin at normal terrestrial barometric pressure. In the course of the experiments, the functions of the subjects' CNS, respiratory, and cardiovascular systems, and their gas metabolism, heat metabolism, and speech and writing were studied. Observations were also made of their behavior, and their morale was evaluated.

As a result of these experiments, it was established that a helium medium, because of its high-heat conductivity, produces basic changes in the heat metabolism of humans. If the comfortable temperature range in an air medium is from $18^{\circ}\text{--}24^{\circ}\text{C}$, then in a helium-oxygen medium the

temperature comfort zone for subjects in the working state during the daytime will be between the limits of 24.5-27.5°C, and at night while asleep between the limits of 26-29°C. The experimental data examined were obtained mostly with the cabin gas medium at comfortable temperatures.

Investigation of the CNS functions showed that in the course of prolonged experiments, a gradual increase of inhibitory processes in the cerebral cortex of the subjects occurred. This was shown by a gradual increase of the slow rhythms on the EEG, and also by a slight lengthening of the latent period of the conditioned motor reactions. Analysis of the experimental data shows that the changes are not caused by the replacement in the atmosphere of nitrogen with helium, but by the effect of prolonged hypodynamia and relative isolation. The general morale, behavior, and work capacity of the subjects in a helium-oxygen medium did not change.

The indices of external respiration, and the cardiovascular system, gas metabolism, and energy expenditure indices of the subjects (under conditions of basal metabolism and in a state of comparative rest) underwent no essential changes. However, functional tests in the form of measured physical loading (physical exercises) showed that as the duration of the experiment was increased, a gradual increase occurred in RMV, frequency of cardiac contractions, oxygen requirement, and energy expenditure. The changes were also unrelated to the effect of the helium-oxygen medium, but were caused by prolonged hypodynamia.

The investigation showed that exposure to a helium-oxygen medium caused essential changes in the speech processes of the subjects, consisting of a speech spectrum shift toward higher frequencies amounting to approximately 0.7 octaves. Distinctness of speech simultaneously deteriorated somewhat, but did not drop below permissible intelligibility limits. The auditory function of the subjects in a helium-oxygen medium underwent no noticeable changes.

On the basis of the experiments conducted, the possibility of prolonged (up to 25 days) sojourns by humans in a hermetically sealed cabin in which the nitrogen of the air has been replaced with helium has been established.

The majority of investigators consider that the atmosphere of the the spacecraft must be completely free from accumulated CO_2 formed as the result of metabolic processes. However, several authors are of the opposite opinion and recommend that the excess CO_2 be used for oxygen regeneration in photosynthesis systems, for treating hypocapnia resulting from certain flight situations, and even for reducing the harmful effects of cosmic radiation. All of this indicates the necessity for

conducting experiments designed for study of the effects of increased CO_2 concentrations in combination with various spaceflight factors (acceleration, hypoxia, hypodynamia, isolation, rarefied atmospheres, and others) and for determining the permissible limits of CO_2 concentration with regard to prolonged sojourns by humans in closed chambers of limited volume.

In our investigation it was shown that a prolonged (up to 30 days) sojourn by humans in an atmosphere with an increased (up to 1 percent concentration) had no essential effect on the general condition and work capacity of the subjects.

Under the same experimental conditions, increase in the partial CO_2 pressure up to 14.9 - 16.7 mm Hg was accompanied by the accumulation in the blood of free and chemically-bound CO_2 up to the levels characteristic of hypercapnia.

As a result of prolonged sojourns in a hermetically-sealed chamber of small volume, the subjects developed symptoms of general asthenia, accompanied by increased pulse lability and lengthening of the time required for its restoration in response to physical loading; lowered oxygen requirement; deterioration of isometric tolerance and isotonic strength indices in individual muscle groups; lowered resistance to acceleration; the onset of irritability and fatigue; decreased appetite; and deterioration of the ability to perform set tasks at the end of the experiment. The institution of a special set of physical exercises eliminated many of the unpleasant effects of hypodynamia.

The data obtained significantly broaden the medical-biological and engineering capabilities of specialists working on the development of life-support systems for spaceflight, and may be used in selection and formulation of atmospheres for the cabins of flight craft.

Translated for the National Aeronautics and Space Administration
by John F. Holman and Co. Inc.

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